

Improved Conditioning for Biosolids Dewatering in Wastewater Treatment Plants

by

Vu Hien Phuong To

A thesis submitted to fulfilment
of the requirements for the degree of
Master of Engineering (by Research)



University of Technology, Sydney

Faculty of Engineering and IT

July, 2015

CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:



Date: 15 / 07 / 2015

ACKNOWLEDGEMENT

I would like to express my special appreciation and thanks to my principal supervisor Dr. Tien Vinh Nguyen and my co – supervisor Professor Saravanamuthu Vigneswaran.

I would like to thank them for encouraging my research and for allowing me to grow as a research scientist. Their advice on both research as well as on my career have been priceless. Without their supervision and constant help this thesis would not have been possible.

I would also like to thank all academic staffs of The Centre for Technology in Water and Wastewater (CTWW) for their valuable advices, comments, suggestions as well as encouragement during my study. A special thank to Mohammed Jorhir, laboratory manager, for his useful helps and advice for my research. I also want to thank Dr Nga Pham, Dr S. Jeong, Thuy Chung Nguyen for their helpful guidance of laboratory skills. Thanks to all my colleagues of CTWW for their support and encouragement.

In addition, I would like to thank Professor Long Nghiem and all colleagues in School of Civil Mining and Environmental Engineering, University of Wollongong, for assisting with Modified Centrifugal Index (MCI) tests and also to MAU (Microstructural Analysis Unit), Faculty of Science, University of Technology, Sydney for their technical support.

My special thanks to Sydney Water Corporation for their supports of both finance and knowledge for my research. My great appreciation for Dr. S. Murthy, Innovations Chief for the District of Columbia Water and Sewer Authority (DC Water) and Prof. M. Higgins from Buckell University, US, who have significant experience in the research

area, by virtue of their helpful consultancy for my study. Also, a grateful thank to UTS International Research Scholarship (UTS IRS) for tuition fee support for my study of Master Degree.

The last but not least, I would like to send my special thanks to family and all of my friends. They were always supporting and encouraging me with their best wishes.

TABLE OF CONTENTS

Title page	i
Certificate of Original Authorship	ii
Acknowledgement	iii
Table of contents	v
Nomenclature	ix
List of abbreviations	x
List of tables	xi
List of figures	xiii
Abstract	xvii

CHAPTER 1

INTRODUCTION	1-1
--------------	-----

1.1. Background	1-2
1.2. Research objectives	1-4
1.3. Scope of the study	1-5

CHAPTER 2

LITERATURE REVIEW	2-1
-------------------	-----

2.1. Sewage sludge	2-2
2.1.1. Classifications, sources and quantities	2-2
2.1.2. Sludge characteristics	2-5
2.2. Sewage sludge treatment	2-8
2.2.1. Sludge thickening	2-9
2.2.2. Sludge stabilization	2-12
2.2.3. Sludge conditioning	2-14

2.2.4.	Sludge dewatering	2-17
2.3.	Chemical conditioning of sludge	2-20
2.3.1.	Polymer conditioning	2-20
2.3.1.1.	Polymer demand for conditioning	2-20
2.3.1.2.	Mixing intensity for conditioning	2-21
2.3.2.	Other chemical conditioning methods	2-23
2.3.2.1.	Dual conditioning	2-23
2.3.2.2.	Advanced oxidation (Fenton) conditioning	2-26
2.4.	Indicators for sludge dewaterability	2-27
2.4.1.	Challenges in measuring sludge dewatering performance	2-27
2.4.2.	Indicators for dewatering by filtration processes	2-30
2.4.3.	Indicators for dewatering by centrifugation processes	2-32
2.4.4.	Other techniques for dewaterability measurements	2-35
2.4.3.1.	Moisture distribution	2-36
2.4.3.2.	Rheology	2-38
2.4.5.	Assessment of dewaterability indicators	2-39

CHAPTER 3

MATERIALS AND METHODS	3-1
3.1. Materials	3-2
3.1.1. Sludge	3-2
3.1.2. Chemicals	3-6
3.2. Experimental studies	3-8
3.2.1. Sludge characterization	3-8
3.3.1.1. Filtrate preparation	3-8
3.3.1.2. Analysis methods	3-8
3.2.2. Conditioning tests	3-9
3.2.2.1. Polymer conditioning – Determining optimal conditioning regimes	3-9
3.2.2.2. Conditioning using other chemicals	3-11
3.2.3. Modified centrifugal index (MCI) test	3-12

CHAPTER 4

RESULTS AND DISCUSSION	4-1
4.1. Sludge characterization	4-2
4.1.1. Wollongong WWTP	4-2
4.1.1.1. Anaerobically digested sludge (ADS)	4-2
4.1.1.2. Dewatered cake and centrate	4-3
4.1.2. St. Marys WWTP	4-5
4.1.2.1. Aerobically digested sludge (AEDS)	4-5
4.1.2.2. Dewatered cake and filtrate	4-7
4.1.3. Quakers Hill WWTP	4-7
4.1.3.1. Waste activated sludge (WAS)	4-7
4.1.3.2. Dewatered cake and centrate	4-9
4.1.4. Feed sludge characterization – Prediction of sludge conditioning demand and dewaterability	4-11
4.2. Effects of sludge characteristics on sludge conditioning and dewatering	4-13
4.2.1. Sludge properties in relationships with conditioning and dewatering	4-13
4.2.1.1. For each sludge type	4-13
4.2.1.2. For all sludge types	4-20
4.2.1.3. Soluble COD as a surrogate measure of soluble biopolymers	4-24
4.2.2. Selection of appropriate polymer type for an effective sludge dewatering	4-24
4.3. Conditioning tests – Determination of optimal conditioning regimes	4-28
4.3.1. Determination of optimal mixing intensity	4-28
4.3.2. Determination of optimal polymer demand (OPD)	4-29
4.3.2.1. Wollongong WWTP – ADS	4-30
4.3.2.2. St. Marys WWTP – AEDS	4-31
4.3.2.3. Quakers Hill WWTP – WAS	4-32
4.4. Modified centrifugal index (MCI)	4-33
4.4.1. Effects of centrifugal intensity (gt) on solids cake content	4-33
4.4.2. MCI tests – Prediction of maximum cake solids content achievable by centrifuge	4-36
4.4.3. MCI tests – Determination of Optimal Polymer Dose (OPD)	4-38

4.4.4.	MCI tests – Effect of digestion on sludge dewaterability	4-42
4.5.	Other chemical conditioning methods	4-44
4.5.1.	Dual conditioning	4-44
4.5.1.1.	Dual polymer conditioning–Cationic/Anionic polymers conditioning	4-44
4.5.1.2.	Iron/Cationic polymer conditioning	4-46
4.5.2.	Advanced oxidation (Fenton) conditioning	4-49

CHAPTER 5

CONCLUSION	5-1
------------	-----

5.1.	Conclusion	5-2
5.1.1.	Sludge characteristics in relationships with sludge conditioning demand and dewatering	5-2
5.1.2.	Comparisons of different indicators for sludge conditioning and dewatering	5-2
5.1.2.1.	Traditionally used indicators	5-2
5.1.2.2.	Modified centrifugal index (MCI) – A new centrifuge based laboratory scale sludge dewatering	5-3
5.1.3.	Other chemical conditioning methods as promising solutions for saving of chemical cost	5-4
5.2.	Recommendations	5-4

REFERENCES

APPENDIX	A-1
----------	-----

List of Publications based on this research	A-2
Sludge characteristics on different sampling times	A-3
Dewatering equipment in 3 WWTPs studied	A-9
Treatment processes of 3 WWTPs studied	A-10

NOMENCLATURE

G = Velocity gradient (s^{-1})

g = Times gravity

R^2 = Correlation coefficient

LIST OF ABBREVIATIONS

ADS	Anaerobically Digested Sludge
AEDS	Aerobically Digested Sludge
BOD	Biochemical Oxygen Demand
CST	Capillary Suction Time
DS	Dry Solids
MCI	Modified Centrifugal Index
OPD	Optimal Polymer Demand
PD	Polymer Demand
rpm	revolution per minute
sCOD	Soluble Chemical Oxygen Demand
sP	Soluble Protein
sPS	Soluble Polysaccharides
SS	Suspended Solids
VS	Volatile Solids
WAS	Waste Activated Sludge
WWTP	Wastewater Treatment Plant
ZP	Zeta Potential

LIST OF TABLES

Table 2–1	Sludge characteristic parameters
Table 2–2	Characterization of wastewater sludges and their dewaterability
Table 2–3	Typical solids concentration for various thickening methods
Table 2–4	Comparison of anaerobic and aerobic digestions
Table 2–5	Summary of sludge conditioning methods
Table 2–6	Comparison of typical mechanical dewatering equipment
Table 2–7	Techniques for predicting dewatering performance of filtration devices
Table 2–8	Sludge dewaterability classifications for centrifuge
Table 3–1	General information on 3 WWTPs studied
Table 3–2	Sludge characteristic parameters measured in the study
Table 3–3	Properties of the polymer used in the study
Table 3–4	Concentration of conditioning polymers at 3 WWTPs studied
Table 3–5	Conditioning tests and chemical used
Table 3–6	Conversion between times gravity and centrifuge rotor speed for 7cm of rotor radius
Table 4–1	Characteristics of ADS, dewatered cake and centrate of Wollongong WWTP
Table 4–2	Characteristics of AEDS, dewatered cake and centrate of St. Marys WWTP
Table 4–3	Characteristics of WAS, dewatered cake and centrate of Quakers Hill WWTP
Table 4–4	Relationships (R^2) of sludge characteristics with OPD and CST for

ADS, AEDS, WAS and all sludge types

Table 4–5	Relationships (R^2) of sCOD with soluble biopolymers for ADS, AEDS, WAS and all sludge types
Table 4–6	Optimal mixing intensity for conditioning of ADS, AEDS and WAS
Table 4–7	Comparison of OPD determined by traditional indicators (CST and ZP) and polymer dose currently used at Wollongong WWTP
Table 4–8	Comparison of OPD determined by traditional indicators (CST and ZP) and polymer dose currently used at St. Marys WWTP
Table 4–9	Comparison of OPD determined by traditional indicators (CST and ZP) and polymer dose currently used at Quakers Hill WWTP
Table 4–10	Maximum cake solids content determined by MCI tests and full-scale processes for 3 sludge types
Table 4–11	Effects of dual polymers conditioning on CST values of conditioned sludge
Table 4–12	Effects of Iron/Cationic polymer conditioning on CST values of conditioned sludge
Table 4–13	Effects of Fenton oxidation conditioning on CST values of conditioned sludge

LIST OF FIGURES

- Figure 2–1 Relationship of sludge solids concentration with residual phosphorus concentration (Xie et al., 2005)
- Figure 2–2 A typical wastewater treatment process and sludge generation
- Figure 2–3 Relationship of cake solids content and sludge volume
- Figure 2–4 A typical sludge treatment process and dry solids content of sludge after different treatment steps (Manzel, 1989)
- Figure 2–5 Effects of feeding solids on performance of a rotary vacuum filter (EPA, 1984)
- Figure 2–6 Summary of dewatering methods (Sanin et al., 2011, Turovskiy and Mathai, 2006, Vigneswaran and Aim, 1989)
- Figure 2–7 Determination of optimal polymer dose for sludge conditioning using (a) SRF (Sanin et al., 2011) and (b) CST measurements (Novak, 2006)
- Figure 2–8 Calibration curve for determining velocity gradient (G) as a function of mixer speed (rpm) (Higgins et al., 2006)
- Figure 2–9 Illustrated mechanism of alum sludge conditioned with combination of anionic polymer (PAA) and cationic polymer (Percol) (Fan et al., 2000)
- Figure 2–10 Two phases of sludge dewatering (Novak et al., 1999)
- Figure 2–11 (a) A traditional SRF measurement apparatus set-up (Sanin et al., 2011) and (b) the schematic diagram of the CST apparatus (Vesilind, 1988)

- Figure 2–12 The schematic diagram of centrifuge (Wakeman, 2007)
- Figure 2–13 Schematics of the arm–suspended centrifuge (Chu and Lee, 2001)
- Figure 2–14 (a) Relationship between bound water content and cake solid concentration (Subramanian, 2005) and (b) relationship between sludge water content and dewatering energy demand (Mowla et al., 2013b)
- Figure 2–15 (a) Shear stress–shear rate rheogram (Abu-Orf and Dentel, 1999) and (b) torque rheogram of unconditioned and conditioned sludge with different polymer doses (Örmeci, 2007)
- Figure 3–1 Bench – scale agitator used for conditioning tests in the study
- Figure 3–2 (a) The standard CST apparatus and (b) determination of optimal polymer dose for sludge conditioning using CST test (Novak, 2006)
- Figure 3–3 (a) Lab – scale centrifuge and (b) Modified centrifuge cup before (left) and after (right) MCI test
- Figure 4–1 (a) ADS; (b) Dewatered cake and (c) Centrate of Wollongong WWTP
- Figure 4–2 (a) AEDS; (b) Dewatered sludge and (c) Filtrate of St. Marys WWTP
- Figure 4–3 (a) WAS; (b) Dewatered sludge and (c) Centrate of Quakers Hill WWTP
- Figure 4–4 Relationships between CST and sludge characteristics including: (a) Soluble COD; (b) Soluble Protein; (c) Soluble Polysaccharides and (d) Total soluble biopolymers for ADS

- Figure 4–5 Relationships between OPD and sludge characteristics including: (a) Soluble COD; (b) Soluble Protein; (c) Soluble Polysaccharides; (d) sP/sPS and (e) Total soluble biopolymers for ADS
- Figure 4–6 Relationships between OPD and sludge characteristics including: (a) Soluble COD; (b) Soluble Protein; (c) Soluble Polysaccharides and (d) Total soluble biopolymers for AEDS
- Figure 4–7 Relationships between OPD and sludge characteristics including: (a) Soluble COD; (b) Soluble Protein; (c) Soluble Polysaccharides and (d) Total soluble biopolymers for WAS
- Figure 4–8 Relationships between CST and sludge characteristics including: (a) Soluble Protein; (b) Soluble Polysaccharides and (c) Total soluble biopolymers for all sludge types
- Figure 4–9 Relationships between OPD and sludge characteristics including: (a) Soluble COD; (b) Soluble Protein; (c) Soluble Polysaccharides and (d) Total soluble biopolymers for all sludge types
- Figure 4–10 Conditioning mechanisms based on relationships between OPD and soluble biopolymer content of ADS and WAS
- Figure 4–11 Relationships between OPD and shear intensity (Gt) for ADS conditioned with zetag8165 and zetag8180
- Figure 4–12 OPD determination by CST tests for WAS conditioning (sample on 3/3/2014)
- Figure 4–13 Effect of gt on cake solids content of unconditioned and conditioned

(PD = 12kg/t DS) ADS

Figure 4–14 Effect of gt on cake solids content of unconditioned and conditioned
(PD = 10kg/t DS) AEDS

Figure 4–15 Effect of gt on cake solids content of unconditioned and conditioned
(PD = 6kg/t DS) WAS

Figure 4–16 Cake solids content of conditioned (a) ADS; (b) AEDS and (c) WAS at
different polymer dosages

Figure 4–17 Effect of polymer dose on SS in the centrate of the MCI tests for (a)
ADS; (b) AEDS and (c) WAS

Figure 4–18 Effect digestion on dewaterability (cake solids content) of (a)
unconditioned and (b) conditioned ADS, AEDS and WAS

ABSTRACT

The aims of this study were to (i) characterize different sludge types, which were anaerobically digested sludge (ADS), aerobically digested sludge (AEDS) and waste activated sludge (WAS) obtained from 3 Wastewater Treatment Plant (WWTP) of Sydney Water, Australia, for the purpose of determining feasible correlations of sludge properties with polymer demand (PD) for sludge conditioning and dewatering, and (ii) apply a new method, namely “Modified Centrifugal Index” test, in evaluating the dewaterability of these sludges after dewatering as well as determining optimal polymer demand (OPD). Besides polymer conditioning, the study also (iii) investigated several conditioning methods using other chemicals such as dual conditioning (Cationic/Anionic polymers and Iron/cationic polymer conditionings) and Fenton oxidation for improving/maintaining sludge dewaterability while reducing the chemical cost of sludge treatment.

It is believed that a comprehensive understanding of the sludge characteristics is essential for optimizing the dewatering process. The study results of sludge characteristics show that ADS required the highest polymer demand for conditioning compared to the other sludge types studied. On the contrary, WAS required the least amount of polymer. The study also proved that there were good correlations between soluble biopolymers (mainly protein and polysaccharides) and OPD, which highlights the major role of soluble biopolymers in deciding polymer demand for sludge conditioning. Besides, these relationships could provide helpful information on suitable polymer types and dosages for an effective sludge conditioning.

Although CST is the most common parameter to evaluate the solid – liquid separation ability, it is often not a reliable indicator. In this study, a modified laboratory – scale centrifuge apparatus was employed. The experimental results show that Modified centrifugal index (MCI) test can be successfully used to evaluate the dewaterability of different sludge types with and without conditioning by estimating the maximum solids cake achievable by the centrifuge. After conditioning and centrifuge, solids contents were increased from 16% to almost 30% for ADS and from 19% to 23% for WAS. These values were similar to the results observed in real WWTPs. This demonstrates that MCI measurement is good to estimate the final cake concentration as well as simulate the real centrifuge process. This method can also help to determine optimal polymer demand (OPD) required for sludge conditioning.

Based on both CST and MCI tests, lower polymer doses than currently used ones were found to be suitable for sludge conditioning of these 3 WWTPs. This could lead to an implication of reducing a significant amount of expensive cationic polymers for sludge conditioning at these plants.

Conditioning methods using other chemicals (besides cationic polymers) which are also promising solutions for replacing expensive conditioners in the WWTPs were demonstrated to improve sludge dewaterability in term of CST. However, full – scale trials or MCI test are needed in the future study to confirm this finding.